Canadian Technical Report of
Fisheries and Aquatic Sciences 1328

December 1984

FRESHWATER INSTITUTE PRIMARY PRODUCTION MODEL USER'S GUIDE

by

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This is the 174th Technical Report
from the Western Region, Winnipeg

Cat. no. Fs 97-6/1328E ISSN 0706-6457

Correct citation for this publication is:

Fee, E.J. 1984. Freshwater Institute primary production user's guide. Can. Tech. Rep. Fish. Aquat. Sci. 1328: v + 36 p.

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ABSTRACT

Fee, E.J. 1984. Freshwater Institute primary production model user's guide. Can. Tech. Rep. Fish. Aquat. Sci. 1328: v + 36 p.

This report describes the numerical model that is used at the Freshwater Institute for estimating phytoplankton primary production. This model runs on 8 or 16 bit personal computers controlled by the CP/M operating system. It is written in PL/1 and can therefore be transported to any computer that has a PL/1 compiler. The theory of the model is presented in detail along with instructions for use. Example data sets and resulting output are shown for each of the programs in the model.

Key words: phytoplankton; limnology; oceanography; trophic dynamics; computer; simulation.

RESUME

Fee, E.J. 1984. Freshwater Institute primary production model user's guide. Can. Tech. Rep. Fish. Aquat. Sci. 1328: v + 36 p.

Ce rapport décrit le modèle numérique utilisé à l'Institut des eaux douces pour évaluer la production primaire de phytoplancton. Ce modèle fonctionne sur des ordinateurs individuels 8 ou 16 bits à système d'exploitation CP/M. Il est rédigé en PL/1 et peut par conséquent être utilisé sur tout ordinateur à compilateur PL/1. Le rapport présente en détail la théorie du modèle ainsi que son mode d'utilisation. Il présente des exemples de fichiers et le résultat final de chacun des programmes du modèle.

Mots-clés: phytoplancton; limnologie; océanographie; dynamique trophique; ordinateur; simulation.

1. INTRODUCTION

Estimating phytoplankton primary production is an important part of several research projects at the Freshwater Institute. The method that we use is based on the measurement of the relation between photosynthesis and light under controlled laboratory conditions. A computer model combines these "incubator" data with in situ transparency and solar irradiance data to yield in situ production estimates (see Fee (1973a) for a general description of the method).

The computer model that is the core of this method has been rewritten several times during the last 15 years (Fee 1969, 1973b, 1977). The version currently in use at the Freshwater Institute has a number of new features which include:

- It runs on inexpensive personal computers. Previous versions required mainframe computers.
- It is written in PL/I and is consequently easier to understand and modify than the previous FORTRAN versions.
- It generates cloudless surface irradiance data for any location on the earth (previous versions had to be reprogrammed for latitudes other than 50° N).
- It provides separate estimates of production in the mixed layer and the hypolimnion.
- It provides estimates of the daily mean irradiances in the mixed layer and in the hypolimnion. These values are useful for determining the degree to which light limits primary production (Hecky and Guildford 1984).
- It calculates the total mass of carbon produced in a lake, correcting for the fact that the volume of the lake decreases as a function of depth (see Fee (1980) for a discussion of the importance of morphometry correction).
- It is based on input of photosynthetic parameters rather than tables of raw photosynthesis vs light data. This reduces the probability of inputting bad data and makes it suitable for estimating production from remotely sensed chlorophyll data.
- Data entry is greatly simplified from previous versions and all input data are checked for plausibility.
- It can be interrupted at any point and later restarted without losing intermediate results.
- It can estimate production for any number of isolated dates and any number of different stations in a single "run".

This manual describes this primary production model. It is assumed that you know how to turn on your computer, insert floppy discs, etc. In order to

effectively use these programs you will also need a rudimentary knowledge of the CP/M operating system (how to enter data into disc files, display the contents of a disc file on the screen, display the disc directory, etc.). All of this information is contained in the operators manual and the CP/M manual for your personal computer.

1.1 SCOPE AND DESIGN OF THE MODEL

These programs are used by limnologists and oceanographers engaged in research on the dynamics of phytoplankton populations. Six programs are included in the model:

- o FITSOLAR - Estimates a constant that describes how atmospheric factors (e.g. haze, altitude) locally modify the global cloudless irradiance equation.
- o PSPARMS - Calculates photosynthetic parameters from incubator data.
- o YEARPROD - Calculates production at one station for a range of dates (usually an entire year).
- o DAYPROD - Calculates production at any number of stations for individual dates.
- o YTOTALS - Calculates the split of production between the mixed layer and the hypolimnion (optionally corrected for morphometry) and the mean light in these layers at one station for a range of dates (usually an entire year).
- o DTOTALS - Calculates the split of production between the mixed layer and the hypolimnion (optionally corrected for morphometry) and the mean light in these layers for single dates at any number of stations.

At the Freshwater Institute these programs are used in the context of research programs that operate in the following way:

- o Integrated water samples are taken from a waterbody at time intervals of approximately two weeks.
  - If the waterbody is stratified, the mixed layer, the thermocline, and the hypolimnion are sampled separately.
  - The transparency of the waterbody is measured at approximately 2-week intervals with a quantum sensor fitted with a flat-late cosine corrected collector.
  - Surface solar irradiances are measured continuously with a quantum sensor located at the central laboratory.
- o In the laboratory the following analyses are made on each water sample.
  - Subsamples are taken for determination of dissolved inorganic carbon and chlorophyll concentrations.
  - 12 or more ground-glass stoppered bottles are filled by siphoning from the remaining sample.
  - ^{14}C is added to these bottles and they are placed in the dark and at five or more light levels in an artificial light incubator for 2-4 hr.

Light levels in the different chambers of the incubator are measured with a spherical quantum sensor 2-3 times during the incubation.
- At the end of the incubation, five mL aliquots from each bottle are placed in scintillation vials and inorganic ^{14}C is stripped out by lowering the pH to 2-3 with HCl and bubbling with air for 15-20 minutes.
- Fluor is added to the vials and the ^{14}C activity is determined in a liquid scintillation spectrometer.

- o Photosynthesis rates are calculated from data on the the ^{14}C uptake rates and dissolved inorganic carbon concentrations.

- o PSPARMS is used to estimate the photosynthesis parameters.

- o YEARPROD or DAYPROD are used to generate in situ productivity profiles.

- o YTOTALS or DTOTALS are used to morphometry correct the productivity profiles and to determine the split of production between the mixed layer and the hypolimnion.

The model was implemented as a collection of separate programs that perform distinct jobs rather than as a single large program that tries to do everything. Experience has shown that this software "tools" approach provides a more flexible data processing environment. Individual tools are more easily modified for specialized research purposes and investigators must learn only the programs that they need for their specific application. Some examples of applications where this "toolkit" approach pays off are:

- o Those working with laboratory or in situ cultures may want to calculate photosynthesis parameters and will need only PSPARMS.

- o Those who want to convert remotely sensed chlorophyll and transparency data into productivity estimates for large lakes will need only YEARPROD and/or DAYPROD.

- o Those who are using empirical solar irradiance data as input to the model will not have any need for FITSOLAR.

1.2 SYSTEM REQUIREMENTS

At the Freshwater Institute this model has been used on Zenith Data Systems Z-100, Z-90 and H-89 computers. It will run "as is" on any microcomputer that has the following hardware:

- o An 8080, 8085, Z80, 8086 or 8088 central processor.

- o At least one disc drive.

- o A minimum of 64K (8-bit machines) or 128K (16-bit machines) bytes of memory.

You will also need the following software:

- CP/M, version 2.2 (8-bit machines) or CP/M-86 (16-bit machines). These operating systems are supplied by Digital Research, Pacific Grove, Calif.
- A text editing program for entering data into disc files (we use VEDIT, Compuview Products, Ann Arbor, Michigan).
- If you plan to modify the programs you will need the Digital Research PL/I-80 (8-bit machines) or PL/I-86 (16-bit machines) compiler.

1.3 REQUIRED INPUTS AND UNITS OF THE DATA

The following table shows which variables are used by which programs and the required units of the data.

Table 1. The variables used in the model, required units, and which programs use them.

Variable	Units	Used By
Latitude	degrees (north positive)	FITSOLAR
Midday Cloudless Irradiance	milliEinsteins/(m^2.min)	FITSOLAR
Chlorophyll	mg/m^3	PSPARMS, YEARPROD, DAYPROD, YTOTALS, DTOTALS
Incubator Irradiance	microEinsteins/m^2.sec	PSPARMS
Incubator Photosynthesis Rate	mg C/(m^3.hr)	PSPARMS
Solar Irradiances	milliEinsteins/(m^2.min)	YEARPROD, DAYPROD, YTOTALS, DTOTALS
In situ Transparency	any units	YEARPROD, DAYPROD, YTOTALS, DTOTALS
α	mg C/(mg chl.Einstein.m^{-2})	YEARPROD, DAYPROD
P_m^B	mg C/(mg chl.hr)	YEARPROD, DAYPROD
Mixing depth	meters	YTOTALS, DTOTALS
Hypsographic data	meters^2	YTOTALS, DTOTALS

- o FITSOLAR needs the latitude, the date (year, month, day) and values of midday solar irradiance. This program is interactive and reads input from the terminal.

- o PSPARMS reads the following "incubator" data from a disc file:
  - Chlorophyll concentration for the sample.
  - Incubator irradiances.
  - Rates of photosynthesis at the specified irradiances.

- o YEARPROD and DAYPROD read the following data from disc files:
  - Surface solar irradiances for the period for which production is to be calculated. These data are input as tables of instantaneous values at time intervals of 30 minutes. If a disc file with these data in it can't be found, cloudless irradiances will be automatically generated.
  - _In situ_ transparency
  - The parameter P_m^B, which is the rate of photosynthesis per unit of chlorophyll at optimal irradiance.
  - The parameter α, which is the slope of the light-limited part of the photosynthesis vs light curve per unit of chlorophyll.
  - Chlorophyll concentration.

- o YTOTALS and DTOTALS read the output disc files of YEARPROD and DAYPROD, respectively, and also read the following data from a disc file:
  - _In situ_ transparency.
  - The depth of the mixed layer.
  - The hypsographic (area vs depth) curve. If these data cannot be found, the totals will not be morphometry corrected.

1.4 MODEL OUTPUTS

- o FITSOLAR displays the fitted constant on the terminal screen.

- o PSPARMS records the fitted parameters in a disc file.

- o YEARPROD and DAYPROD record the following output in a disc file:
  - The depth profile of production for each day.
  - The depth profile of production for the entire time period for which calculations were made.
  - The integral of production for each day.
  - The integral of production for the entire time period for which calculations were made.
  - The values of the input data that were used at each depth where production was calculated.
  - Warning messages (if any).

- o YTOTALS and DTOTALS record the following output in a disc file:
  - The depth of the mixed layer for each day.
  - Uncorrected and (optionally) morphometry corrected production integrals and averages for the mixed layer and for the hypolimnion for each day.
  - Uncorrected and (optionally) morphometry corrected production integrals and averages for the mixed layer and for the hypolimnion for the entire time period for which calculations were made.

- The mean irradiances in the mixed layer and the hypolimnion for each day.

1.5 TIME REQUIREMENTS

The times quoted below are for a Z-100 microcomputer (8085 chip running at 4 MHz). FITSOLAR and PSPARMS use 15-25 seconds for processing a single dataset. DAYPROD requires about the same amount of time to calculate daily production for a single station. YEARPROD takes about 15 minutes to calculate annual production for a lake with a seven month ice-free season. DTOTALS uses about 20 seconds to morphometry correct production totals for a single station. YTOTALS takes about 10 minutes to morphometry correct production totals for a seven month ice-free season.

1.6 COMPARISON TO EARLIER VERSIONS

The new model was used to calculate annual production for lakes at the Experimental Lakes Area for the period 1976-1982. The following table compares the values given by the new model with those given by the old model.

Table 2. Comparison of annual primary production rates in Experimental Lakes Area (ELA) lakes calculated with the old incubator model (Fee 1977) and with the new model presented in this report. Reported values are percentages (new/old).

Lake	1976	1977	1978	1979	1980	1981	1982	
114			97	112	94	107	103	
222		98			96	105	98	
223	94	96	100	97	105	107	109	
224	93	102				107	104	
226N	97	106	92	98	101	104	101	
226S	102	102	100	95	100	106	112	
227	97	95	98	97	94	104	102	
239	91	101	98	98	99	105	102	
261	99	100						
302N	101		98		96	108	101	
302S	98		100		96	102	97	
304	96	99			91		111	
382		104	98	99	92		103	
382B				99	91		103	
383			100	99				
								*****
mean	97%	100%	98%	99%	96%	106%	104%	=> 100%

1.7 AVAILABILITY AND TRANSPORTABILITY

The programs are available from the author on two floppy disc formats:

- o 8" single sided, single density (standard CP/M).
- o 5-1/4" double sided, double density Heath/Zenith CP/M (specify 48 tpi or 96 tpi).

Please specify whether you want the 8-bit or 16-bit version. The source code of the model is contained in 73 disc files. The names of these files and a brief description of their contents are given in Appendix 1. Listings of these files (about 100 pages) will be supplied to users that need to adapt the model to other machines. All but four procedures are written in PL/I. Because the Digital Research compilers conform to the specifications of subset G of the full PL/I language, there will be few problems transporting the code to other machines. See Appendix 1 for more details.

2. THEORY OF THE MODEL

The fundamental difference between the new model and previous versions is that the rate of production at a given irradiance is calculated from an equation based on photosynthetic parameters (P^B_m and α) instead of being calculated by linear interpolation in the raw incubator data. The use of these parameters in studies of phytoplankton ecology is relatively recent (Bannister (1974), Jassby and Platt (1976)) and the following considerations led to their incorporation in the new model:

- o A model based on these parameters can be used to estimate primary production in lakes for which only chlorophyll and transparency data are available.
- o Calculation of these parameters makes it easier to spot errors in the input data and consequently model output is more reliable.
- o By requiring them as input to the model, a valuable database will be created over time. This information will allow us to formulate and test hypotheses about how latitude, turbidity, lake size, acidification, nutrient loading and a multitude of other factors influence P^B_m and α. I is only when we can predict the spatial and temporal variations of these parameters we will be able to reliably estimate productivity from remotely sensed chlorophyll and transparency data.

2.1 GENERAL

This subsection describes constants and algorithms used by more than one program in the model.

2.1.1 Constants

The following constants are incorporated into the model:

- DELTAT - The time interval between successive values of surface solar irradiance. A value of 30 minutes is used. Previous versions of the program used five minutes but test runs showed no differences in daily production for time steps between five and 40 minutes (there were significant differences with a time steps greater than 40 minutes).

- NDEPTHS - The number of layers that the euphotic zone is divided into. The program uses eleven layers. Previous versions of the model used 21 layers but tests with actual data showed that there is no loss of accuracy with eleven.

- EUPI - The fraction of surface light at the bottom of the euphotic zone. The program uses a value of 0.005 (=0.5%).

- MAXDATA - The maximum number of data point pairs that can be input in a single depth profile of transparency, chlorophyll, P_m^B or α. The program uses 50 for this limit.

- NIZERO - The maximum number of data points in a single solar irradiance curve. The program uses 150, which is sufficient for a time step of 10 minutes.

- MINCHL, MAXCHL, MINPARM, MAXPARM, MAXZEUP - As data are read they are checked for plausibility by seeing if they exceed the maxima or minima in the following table:

Table 3. Acceptable ranges of values for variables used in the primary production model.

Variable	Minimum	Maximum
Chlorophyll	0.5	350
α	0.5	10
P_m^B	0.5	10
Euphotic Zone Depth	none	20

If an input datum is greater than the tabled maximum or less than the tabled minimum the program prints a warning message at the end of the computed output and continues with the calculations.

- LATITUDE - The degrees from the equator (north positive) of the waterbody. It is used when the model calculates cloudless solar irradiances (see section 2.1.4) and if you always use empirical solar data you don't have to worry about its value. The default value is 50^oN.

- ATMOS_EFFECT - This is an empirical constant that specifies the fraction of solar irradiance at the top of the atmosphere that reaches the surface of the earth at the location of the waterbody under cloudless conditions. It is used when the model calculates cloudless solar irradiances (see section 2.1.4) and if you always use empirical solar data you don't have to worry about its value. The default value is 0.3563 and was measured at the Experimental Lakes Area in NW Ontario. The program FITSOLAR is used to fit values of this constant for other locations.

The default values of the constants DELTAT, NDEPTHS, LATITUDE and ATMOS_EFFECT can be altered at the time that the programs are run (see section 4.3). To alter the other constants (EUPI, MAXDATA, NIZERO, MINCHL, ...) you must change the value(s) in the file PRODN.REP (see Appendix 1) and recompile the programs.

2.1.2 Missing data

YEARPROD, DAYPROD, YTOTALS and DTOTALS use linear interpolation to obtain values of variables for dates between sampling dates. For example, if you input a chlorophyll value of 1.0 on June 1 and a value of 2.0 on July 1 then the value used on June 10 will be 1.333, on June 15 will be 1.5, and so on.

Certain variables (transparency, chlorophyll, P_m^B, α and hypsographic data) are input as depth profiles (values as a function of depth). If the maximum depth to which production is to be calculated is less than or equal to the maximum depth of the input data, then values for the depths where production is to be calculated are obtained by interpolation in the input data. However, if an input profile does not include data for all depths where values are needed, then the available data are extrapolated in the following way:

- Chlorophyll, P_m^B and α data:
  - If the input does not include a value for the surface, then the value at the shallowest depth that was input is used from the surface down to that depth.
  - If the input must be extrapolated to greater depths than were input, then the value at the greatest depth that was input is used uniformly at all greater depths.

- Transparency and hypsographic data:
  - If a value is not input for a depth of 0 m or if only one value is input, the program prints an error message and stops. At least two data points must be input for each profile because a line must be fit to these data in order to extrapolate them.
  - A straight line is fit to the available data (transparency data are linearized by converting them to logarithms). The slope and intercept of this line are used to compute values at greater depths than were input. For the transparency data, if five or more data points were input, the first three data points that were input are not used in fitting the straight line since the log of transparency vs depth is usually highly nonlinear near the surface.

If you only enter one profile or value it will be extrapolated forward and/or backward in time as needed. For example, if you input an α value date 1 June and request production for the period 1 May through 1 October, the 1 June value will be used for the entire period. Whenever input data are extrapolated in this manner a warning message is recorded along with the output.

2.1.3 Integration method

YEARPROD, DAYPROD, YTOTALS and DTOTALS integrate functions over depth. All integrations are done with Simpson's 3-point numerical integration rule. This algorithm consists of fitting parabolas to successive groups of three points on the curve to be integrated and summing the areas under the individual parabolas. The formula for Simpson's Rule is:

$$\int_{Zt}^{Zb} f(z)dz \simeq (Zb-Zt)\ [y_1+4y_2+2y_3+4y_4+2y_5+\ldots+2y_{n-2}+4y_{n-1}+y_n]\ /\ 3(n-1)$$

where,

f(z) is the function being integrated over depth,

Zt is the depth where the integration starts,

Zb is the depth where the integration ends,

y_k is the k-th value of the function f(z), i.e. $f(Zt)=y_1$, etc.

n is the number of points at which the function is known in the interval (Zb-Zt). Note that this algorithm requires n to be an odd numb

2.1.4 Simulation of cloudless solar irradiances

Solar data generated by the model are scaled in units of milliEinsteins/(m^2.min) and are made specific for each waterbody by the parameters LATITUDE and ATMOS_EFFECT. LATITUDE is the location of the waterbody in units of degrees from the equator (negative for the southern hemisphere). ATMOS_EFFECT is the fraction of the irradiance at the top of the atmosphere that reaches the earth at the location of the waterbody under typical cloudless conditions. Its value depends on air pollution, altitude and other factors.

The following formulas were adapted from Brock (1981) and Davies (1981). The declination of the earth during the year (the angle between the sun and the equator at solar noon, north positive) is calculated with the formula:

$$DECL = 23.44803 * \sin(2 * \pi * (284 + d_n) / y_n)$$

where, π is 3.1415927

d_n is the Julian date

y_n is the number of days in the year

The angle of the sun from due south at sunset is calculated with the formulas:

let f1 = -tan(LATITUDE) * tan(DECL).

Then if f1 > 1 then SUNSET_ANGLE = 0,

else if f1 < -1 then SUNSET_ANGLE = π,

else SUNSET_ANGLE = acos(f1).

The minutes of sunlight during the day is given by the formula:

d_1 = 8 * SUNSET_ANGLE * π / 180

The square of the deviation of the earth from its mean distance from the sun is calculated with the formulas:

Let f2 = 2 * π * d_n / y_n.

Then

DSQ = 1.00011 + 0.034221 * cos(f2) + 0.00128 * sin(f2) -

0.000719 * cos(2 * f2) + 0.000077 * sin(2 * f2).

Finally, using a value of 373.4 mE/(m^2.min) for the SOLAR_CONSTANT (solar irradiance at the top of the atmosphere at the mean solar distance), cloudless irradiances are calculated at 30 minute intervals with the formula:

(ATMOS_EFFECT * SOLAR_CONSTANT / DSQ) *

(sin(DECL) * sin(LATITUDE) +

cos(DECL) * cos(LATITUDE) * cos(MIN_ANGLE))

where, MIN_ANGLE is the angle of the sun from due south at any minute during the day.

2.2 PROGRAM FITSOLAR

a. The upper and lower bounds for the search are set to 1 and 0, respectively.
b. The upper and lower bounds for the search are averaged to obtain a test value (t).
c. A solar irradiance curve is generated using t.
d. If the value of midday irradiance in the generated solar irradiance curve is greater than the observed value then the upper bound for the search is set to t, otherwise the lower bound for the search is set to t.

e. steps b-d are repeated until the difference between the upper and the lower bounds is less than 0.001.

2.3 PROGRAM PSPARMS

The Simplex algorithm is used to find the best fit of the equation given in section 2.3 to the experimental production vs light data. See Caceci and Cacheris (1984) for an explanation of this nonlinear curve-fitting algorithm. Starting values of the parameters are obtained in the following way:

- P_m^B is the maximum value of production in the dataset divided by the chlorophyll concentration.

- α is taken as 5.0 mg C/(mg chl.E.m^{-2}). The reason for taking a fixed value as the starting estimate for this parameter is that unusual datapoints (outliers) can give very bad initial estimates that will prevent the program from converging.

2.4 PROGRAMS YEARPROD AND DAYPROD

These programs begin by calculating the depth of the euphotic zone (the depth where _in situ_ light is 0.5% of surface light) from the input transparency data. The euphotic zone is then divided into discrete layers of equal thickness. Before _in situ_ production can be simulated, values for the following variables must be known at the "calculation depths" (the surface, the bottom of the euphotic zone and at the depths where the layers meet):

- The fraction of the surface solar irradiance that reaches that depth.

- The chlorophyll concentration (chl).

- P_m^B.

- α.

The values of these variables are linearly interpolated for the required depths from the input data. Transparency data are linearized by converting them to logarithms before the interpolation is done and are converted back to linear units after being interpolated. Linear interpolation is also used to obtain values for dates between sampling dates.

After the data are interpolated daily production is simulated in the following way:

- For each value of surface irradiance during the day the following steps are performed for all calculation depths:
  - The absolute irradiance (I) is obtained by multiplying the value of surface irradiance by the fraction of surface light that reaches that depth.
  - Production (P) as a function of irradiance is calculated with the equations:

Let $I_k = P_m^B / \alpha$.

Then if $I \le I_k / 20$ then $P = 0$,

else if $I \ge 2 * I_k$ then $P = chl * P_m^B$,

else $P = chl * \alpha * I' * (1 - \alpha * I' / (4 * P_m^B))$,

where $I' = I - I_k / 20$.

Note that I, I_k, I', chl, α, and P_m^B are all functions of depth.

- The daily total of production at that depth is updated.

o The daily profile is integrated with Simpson's Rule (section 2.1.3) to obtain the daily integral and this value is added to the annual total.

The equation relating production to available light is adapted from one given in Jassby and Platt (1976); it was chosen over their recommended hyperbolic tangent function because it gives identical integral values while requiring only one-fifth of the computer time to evaluate. Production is forced through zero at an irradiance of $I_k/20$; this constant was determined empirically and corresponds to Jassby and Platt's R^B. Note that inhibition of production by high surface irradiances that occur at shallow depths on sunny days is ignored. Marra (1978), and Welschmeyer and Lorenzen (1981) have shown that such inhibition probably does not occur in nature and Fee (1980) showed that it is of little quantitative importance even if it does occur.

The model implicitly assumes that α, P_m^B and transparency do not vary ove the course of the day. These kinds of variation are of secondary importance and for routine purposes are best ignored (Fee 1980).

2.5 PROGRAMS YTOTALS AND DTOTALS

Reasons for not incorporating the functions of these programs into YEARPROD and DAYPROD are:

o It would make those programs very complex and hard to modify.

o Not every application requires production totals split between the mixed layer and the hypolimnion.

o It it advantageous to be able to specify more depth intervals in the euphotic zone when calculating the split of production between the mixed layer and the hypolimnion than were used in the original calculations of production (section 4.4 shows how to do this). For example, suppose that you calculated production at 11 depths (the default) and the euphotic zone depth was 10 meters. Thus, production would be calculated at depth intervals of 1 meter. However, if the depth of the mixed layer was two meters only three production values would be available for calculating the integral in the mixed layer. Such an integration would be very inaccurate. However, if you specify that you want 41 depth intervals when you run the totals program, there will be nine data points for

integrating production in the mixed layer. This will result in similar accuracy for the 0-2 m integral as was obtained for the whole water column by the original production program.

Like YEARPROD and DAYPROD, these programs divide the euphotic zone into discrete layers of equal thickness and calculate values for the following variables at the surface, at the bottom of the euphotic zone and at each of the depths where these layers meet:

- The fraction of solar irradiance that reaches that depth.
- The daily production at that depth.
- The area of the lake at that depth (if morphometry correction is desired).

In addition, the depth of the mixed layer must be known.

Given all of the required variables, it is straightforward to calculate the various totals with Simpson's Rule (section 2.1.3).

3. DATA FORMATS

This section describes how input data must be organized for the different programs in the primary production model. All programs read their inputs in "free-format". This means that it doesn't matter where you type data on an input line - successive values are separated by blanks, commas, tabs or the ends of lines. Further, alphabetic data can be entered in either upper or lower case. "Free-format" does <u>not</u> mean that data can be entered in any <u>order</u>. For example, although it doesn't matter where on a line you type a date, it is very important whether you type the date as "May 1" or "1 May".

3.1 GENERAL

This subsection describes formats that are used by more than one program in the model.

<u>3.1.1 Disc file nomenclature</u>

Except for FITSOLAR, all programs read their input from disc files and write their output into other disc files. Disc files are named in the following way: "NAME.TYP". The file's NAME is what you type when you start a program - it tells the program where the data for it are to be found. The NAME can contain eight or fewer characters. When you create your data files you can make up whatever NAMEs that you wish (e.g. "LWPG69"). The file TYP tells the model what kind of data the file contains (e.g. files with a TYP of "SOL" contain solar radiation data). The file TYP contains three characters. When you create your data files you <u>must</u> give them the proper TYP or they will not be found by the model. The TYPes of files used in the productivity model are given in the following table.

Table 4. Summary of file types used in the model, the uses of each type, and the programs that use each type.

TYP	Use	Used by	Contents
SOL	Input Output	YEARPROD, YTOTALS DAYPROD, DTOTALS	Solar data
INC	Input	PSPARMS	Incubator data
PRM	Output	PSPARMS	Fitted parameters
DAT	Input	YEARPROD, YTOTALS DAYPROD, DTOTALS	Input data
STA	Input	DAYPROD, DTOTALS	Input data for a station
OUT	Output	YEARPROD, DAYPROD	Computed results
TOT	Output	YTOTALS, DTOTALS	Computed results
###	Output	YEARPROD, YTOTALS DAYPROD, DTOTALS	Fatal error messages

3.1.2 Header lines

The first line in any disc file that contains input data can contain any information that you wish to be permanently recorded with the computed output. This "header" usually describes the location, dates, instruments used, etc. Make sure that you don't have a blank line at the start of a data file or it will be taken to be the header line and what you intended to be the header will be read (unsuccessfully) as data.

3.1.3 Dates

Most inputs must be dated. All dates are input as "Month, day" pairs, where the month is alphabetic and the day is numeric, e.g. "May 10". Month names can be shortened to their first three letters (e.g. Aug). The model assumes that all dates are from the same year.

3.1.4 Solar data

Solar data are input as tables (one for each day) that give the instantaneous flux of solar radiation at time intervals of 30 minutes. Data are required only for times when the sun is above the horizon but including zeros for the dark periods does no harm.

A solar file containing data for two days might look like:

```
|ELA Cloudless solar irradiance data.
|May 1
| 0.0  11.9  18.8  27.0  36.2  46.0  56.2  66.5  76.4  85.9
|94.4 101.7 107.7 112.2 114.9 115.8 114.9 112.2 107.7 101.7
|94.4  85.9  76.4  66.5  56.2  46.0  36.2  27.0  18.8  11.9
| 0.0  -1.0
|May 2 0.  11.8  18.4  26.3  35.1  44.6  54.5  64.4  74.2  83.6
|92.1  99.7 106.1 111.0 114.4 116.1 116.1 114.4 111.0 106.1
|99.7  92.1  83.6  74.2  64.4  54.5  44.6  35.1  26.3  18.4
|11.8   0.0  -1.0
```

(In this example and in those which follow the vertical line represents the left edge of each line in the input file.) The file starts with a header line. The table for each day begins with the date. Following the date come the data for that day. A negative light value is interpreted as a signal that all data for that day have been entered. Note that dates don't have to be on separate lines nor do successive tables have to start on new lines. If data for more than one date are included in a SOL file is not necessary that the file contain data for each consecutive day; i.e. the file can contain gaps in the dates. However, data that are present must be in chronological order.

Empirical measurements of solar radiation must be digitized for input to the model. This can either be done with a data logger at the time that the data are collected or the data can be recorded on a strip chart and later digitized with a mechanical pen follower. The model can also use simulated cloudless solar data. The protocol that determines which of these two types of solar data are used is:

- If you want the program to use empirical solar data, then you must put these data in a disc file whose first name is the year for which calculations are to be made and whose last name is "SOL" (e.g. 1976.SOL).

- If a disc file containing empirical solar data cannot be found, the model looks for cloudless solar data in a file called CLDLSS.SOL.

- If neither of the above files can be found then the model generates cloudless solar data for the dates for which calculations are to be made.
  - If YEARPROD is the program generating these data then the generated data are saved in a file named CLDLSS.SOL; these data can then be used by YTOTALS or by subsequent runs of YEARPROD without having to be regenerated.
  - If a disc file containing solar data was found but production is to be calculated for a date for which no data exist in this file, then cloudless weather will be generated for the missing date(s). These newly generated data will not be saved or added to the disc file from which solar data are being read.

3.1.5 Transparency, chlorophyll, P_m^B, and α data

All these data are input as depth profiles. Each depth profile starts with the date. Following the date are pairs of data, the first value in each pair is a depth, the second value is the value of the variable at the depth just specified. A negative value for either the depth or for the value of the variable terminates data input for the profile. For example, a single depth profile of water transparency might look like:

```
|July 17
|0 100
|1 50
|2 25
|3 12.5
|4 6.25
|-1
```

Because data entry is free-format, these data could also be input as:

```
|July 17 0 100, 1 50, 2 25, 3 12.5, 4 6.25, -1
```

Notice that no header lines are shown in these examples. This is because depth profile data are always input as part of a DAT or STA file and it is only the first line of the entire file which contains a header. Note further that the PRM output file produced by PSPARMS is not in the proper format for input of chlorophyll, P_m^B, or α data.

3.1.6 Hypsographic data

If you want YTOTALS or DTOTALS to correct the production values for the decrease of the volume of the lake with depth you must supply hypsographic data. The format of these data is the same as for depth profile data (section 3.1.5) except that no date is attached to them. A hypsographic dataset might look like:

```
|0 27.7E8    2 24.47E8   4 23.90E8   6 21.29E8
|8 17.37E8  10 10.74E8  12 0.65E8   -1
```

The first number in each pair is the depth, the second is the area of the lake at that depth.

3.1.7 Mixing depth data

YTOTALS and DTOTALS require mixing depths to be able to calculate the split production between the mixed layer and the hypolimnion. A set of mixing depth data might look like:

```
|Apr 1       5
|May 1       3
|May 5       6
|May 30      10
```

Note that the programs do not need any negative "end of data" signal to tell where the input for a single date ends since only one value of mixing depth

can be input for each date. Mixing depths can be greater than values in either the hypsographic data or the depths to which production was computed - YTOTALS or DTOTALS will extrapolate those data as necessary to obtain values for greater depths.

3.1.8 Organization of data in DAT files

YEARPROD, YTOTALS, DAYPROD and DTOTALS each read several types of data from a single DAT file. These different data types (transparency, chlorophyll, α, P^B_m, mixing depth, hypsographic data) can be entered in any order in a DAT file. Each data type is separated from the others by a line which has a slash (/) in column 1 followed by three letters which specify the type of data which follow (ext = light extinction, chl = chlorophyll, alp = α pbm = P^B_m, zep = mixing depth, hyp = hypsographic data). See sections 3.4 - 3.7 for examples. The remainder of this line is ignored by the programs and can be used for notes about the data.

3.2 PROGRAM FITSOLAR

This program prompts the user to type the date and a measured value of midday irradiance on that date. It displays the fitted value of ATMOS EFFECTS on the console monitor.

3.3 PROGRAM PSPARMS

This program reads incubator data from a disc file whose second name is INC. This file contains a header line and a tables of incubator data (one for each experiment). The program is very flexible regarding the input of incubator data: 20 or less distinct light levels and five or less replicates at each light level are allowed. A file containing two sets of incubator data might look like:

```
|Yellowknife Lake Study, 1983 Data
|Station-01 5.7
|      13      -1      0.14    -9
|      39.2    -1      0.67    0.78    -9
|      126.7   -1      2.49    3.05    -9
|      366.7   -1      3.05    3.13    -9
|      -1
|'Station 75' 2.6
|      10.1    12.4    -1      0.11    -9
|      27.3    -1      0.57    0.57    -9
|      57.5    -1      1.49    1.62    -9
|      125.6   -1      5.36    3.57    -9
|      289.2   -1      4.80    -9
|      -1
```

Incubator data are interpreted in the following way:

- o The first line in the file is a header line.
- o Each incubator dataset starts with an identifier (e.g. Station-01). If

this identifier contains blanks you must enclose it in single quotes (').

- o Following the identifier comes the chlorophyll concentration.

- o Light values for the first incubator chamber follow the chlorophyll concentration. Any number of replicate measurements can be entered; the end of a set of replicates is signalled by a negative value. The replicate light measurements are averaged to obtain a single value that is paired with the photosynthesis rates that were measured at this light level. This allows you to enter all light measurements for a single incubator "chamber" without having to manually average them beforehand.

- o Following the light measurements come the corresponding photosynthesis measurements. The program keeps reading successive photosynthesis values for a chamber until a number less than or equal to -5 is entered. The replicates of photosynthesis are <u>not</u> averaged before being used in the parameter fitting procedure.

- o The above format - light values followed by production values, is repeated for each chamber in the incubator. It doesn't matter whether the incubator data are entered from low irradiances to high or vice versa. A negative value for light terminates input for a single incubator dataset.

3.4 PROGRAM YEARPROD

This program reads data from two disc files:

- o A SOL file that contains solar data (see section 3.1.4).

- o A DAT file that contains:
  - The starting and ending dates for which calculations are to be made.
  - Depth profiles of chlorophyll, transparency, α and P_m^B.

A DAT file for YEARPROD might look like:

```
|Lake Winnipeg 1976, Cruise 3
|May 1, May 10, 1976
|/ext
|May 5       0      100     10      1      -1
|/chl
|May 1       0      1       -1
|May 10      0      10      -1
|/alp
|Jan 1       0      5       -1
|/pbm
|Dec 31      0      1.98    -1
```

This file is interpreted in the following way:

- o The first line is a header.

- o The starting and ending dates for which production is to be calculated

are entered next. These dates must both be in the same year. This means that separate runs must be made if the period for which production is to be calculated extends past the end of a year (e.g. production for the period Oct 20, 1976 to Mar 31, 1977 would have to be done in two runs: Oct 20, Dec 31, 1976 and Jan 1, Mar 31, 1977).

- The year for which production is to be calculated is input next.

- Depth profiles of transparency, chlrophyll, α and P_m^B follow. See sectio 3.1.8 for a description of the organization of these data in DAT files.

3.5 PROGRAM DAYPROD

This program reads data from three files:

- A SOL file that contains solar data (see section 3.1.4).

- A STA file that contains a header line for the entire run and a list of station identifiers.

- A DAT file (one for each station named in the STA file) that contains the input for that station. Each DAT file contains:
  - A header line for that station.
  - The date for which production is to be calculated.
  - The year.
  - Depth profiles of transparency, chlorophyll, α and P_m^B.

A STA file for DAYPROD might look like:

```
|Lake Winnipeg 1976, Cruise 3
|318
```

This data is interpreted in the following way:

- The first line is a header.

- The NAME(s) that follow (they don't have to be on separate lines) point to separate DAT disc files, each of which has a TYPe of DAT. DAT files for DAYPROD contain data which is identical in format to DAT files used by YEARPROD except that only one date is specified instead of a range of dates. Note: to provide a simple example only one station is shown; normally many stations would be listed in this file.

The above STA file points to the file 318.DAT, which might look like:

```
|L. Wpg, Station 318, 1976   Cloudless weather
|Jun 6 1976
|/ext
|Jun 6
|0     100     2       2.19    -1
|/chl
|Jun 6 0       1.7     -1
|/alp
|Jun 6 0       5.4     -1
|/pbm
|Jun 6 0       4.7     -1
```

The STA file is interpreted in the following way:

- The first line is a header.
- The date and year follow.
- Depth profiles of light extinction, chlorophyll concentration, α and P_m^B follow (see section 3.4 for description of the way these data are organized in DAT files).
  - If a date on any of these profiles do not match the date for which production is to be calculated then a warning message will be recorded along with the computed results.

3.6 PROGRAM YTOTALS

This program reads data from three files:

- A SOL file that contains the solar data that were used to calculate the production results that are to be split into mixed layer and hypolimnion totals.
- The OUT file which contains the computed production profiles. This is the output of YEARPROD.
- A DAT file that contains:
  - A header line.
  - The beginning and ending dates for calculating totals and the year.
  - Light extinction data. This will usually be identical to the data that were in the DAT file used by YEARPROD to compute the production profiles.
  - Mixing depth data (see section 3.1.7 for the format of these data).
  - Hypsographic data (see section 3.1.6 for the format of these data). These are required only if you wish to have the totals morphometry corrected.

A DAT file for YTOTALS might look like:

```
|Lake Winnipeg 1976, Cruise 3
|May 1, May 10, 1976
|/ext
|May 5         0       100     10      1       -1
|/hyp
|0 27.78E8, 2 25.57E8, 4 23.90E8, 6 21.29E8,
|8 17.37E8, 10 10.74E8, 12 0.65E8 -1
|/zep
|May   1       3
|May  30       10
```

This DAT file is interpreted in the following way:

- o The first line is a header.
- o Next come the starting and ending dates for which totals are to be calculated.
- o The year follows the dates.
- o Transparency, mixing depth and hypsographic data follow. See section 3.1.8 for a description of the organization of these data in DAT files.

Note that this DAT file contains different data than the DAT file given as an example in section 3.4. However, this is for purposes of illustration only. In practice, the same DAT file would usually be used as input to both YEARPROD AND YTOTALS, with all data needed by both programs included. Each program will simply ignore data in the file that it doesn't need.

3.7 PROGRAM DTOTALS

This program requires four input data files:

- o The SOL file that was used by DAYPROD to calculate the production profiles that are to be totalled.
- o The OUT file produced by DAYPROD that contains the computed production profiles that are to be totalled.
- o A STA file that contains:
  - A header line.
  - A list of station names.
- o A DAT file (one for each station named in the STA file) that contains:
  - A header line for that station.
  - The date and year.
  - Light extinction data. These will normally be identical to the transparency data that were used by DAYPROD to produce the production profiles that are to be totalled.
- o The mixing depth (see section 3.1.7 for the format of these data).
- o Hypsographic data (see section 3.1.6 for the format of these data).

These are required only if you want the totals to be morphometry corrected.

A STA file for use with DTOTALS would look exactly like the example given in section 3.5. The file 318.DAT pointed to by this example might look like:

```
|L. Wpg, Station 318, 1976   Cloudless weather
|Jun 6  1976
|/ext
|Jun 6
|0      100     2       2.19     -1
|/hyp
|0 27.78E8, 2 25.57E8, 4 23.90E8, 6 21.29E8,
|8 17.37E8, 10 10.74E8, 12 0.65E8 -1
|/zep
|Jun 6  10.0
```

These data are interpreted in the following way:

- o The first line is a header for this station.
- o Next comes the date and year.
- o Light extinction, mixing depth and hypsographic data follow. See section 3.1.8 for a description of the organization of these data in STA files.

Note that this DAT file contains different data than the DAT file given as an example in section 3.4. However, this is for purposes of illustration only. In practice, the same DAT file would usually be used as input to both DAYPROD AND DTOTALS, with all data needed by both programs included. Each program will simply ignore data in the file that it doesn't need.

4. RUNNING THE MODEL

This section describes how to run the programs in the model.

4.1 STARTING THE PROGRAMS

All of the programs in the model are started by typing the name of the program, a space and then the NAME of the disc file (see section 3.1.1) that contains input data for that program. For example, to start the program YEARPROD and tell it that the input data are to be found in the disc file ELA84.DAT you would type:

A><u>yearprod ela84</u>

(The symbols "A>" are the CP/M system prompt, you type the rest - in this and all examples which follow, text that you type is underlined and text that the computer prints on the screen is printed in bold typeface).

Each program starts by printing a banner (its name, the version number, and the date on which this version was created). For example, the following text would appear on the screen if you typed the line above:

Annual Primary Production Program

FWI Software Tools

Version 2.8 - 26/JUN/84

While the program is running it may print informative messages on the screen. For example, YEARPROD may print:

Generating cloudless light data... done

Press B to breakpoint run

The next to the last line indicates that a disc file with solar data could not be found so it generated these data. Only messages such as this appear on the screen - all warning and error messages are permanently recorded in disc file(s) (see section 4.2).

4.2 ERROR HANDLING

When YEARPROD and DAYPROD start up they look through all input data for errors before they actually do any calculations. This ensures that the data are acceptable before the machine starts on a long series of calculations. If questionable data (using the criteria in section 2.1.1) are encountered, the run will continue after a warning message has been recorded. However, if the model cannot recover from the data error, a message will be printed into a disc file with the same NAME as the input data file and a TYP (see section 3.1.1 for definitions of NAME and TYP) of '###'. The reason for having a special file TYP of '###' is that typically many runs are "batched" together for submission to CP/M as a single unit (see the CP/M manual for documentation of the SUBMIT utility that is used for this purpose). When all of the runs have finished you will want to find out which of the runs failed because of data errors without having to print out all of the output for all of the runs. You do this by simply looking at the disc directory for files with TYPes of '###'.

Although YTOTALS and DTOTALS do not check their input data before starting calculations as YEARPROD and DAYPROD do, if any fatal errors are encountered they also record them in a file with the TYPe of '###'.

4.3 BREAKPOINTING RUNS

YEARPROD and DAYPROD have a built-in breakpoint facility that allows you to interrupt the calculations at any point without losing the results that have already been obtained when you restart the run. This is handy if you want to check for data errors before committing the program to a long calculation (see section 4.3) or if you want to use the computer for something else. You breakpoint a run by typing the letter 'B' anytime after the message

"**Press B to breakpoint run**" appears on the screen (see example in section 4.1). When you do this the intermediate results are stored on a disc file with a TYPe of OUT and the same NAME as the NAME which you typed to start the run.

At the point where the run was breakpointed, the OUT disc file will have a backslash ("\") in column 1. This character is a signal to the program that this is the output from an incomplete run. Restart the run by typing in the same command line that was used when the run was first initiated. If the program finds the backslash character the calculations resume at the point where they were interrupted. If it does not find the backslash, the OUT file will be erased if it exists and calculations will start over from the beginning.

4.4 RUN-TIME COMMANDS

YEARPROD, DAYPROD, YTOTALS and DTOTALS incorporate a standard set of constants (see section 2.1.1) and default procedures. You may not always want these programs to operate in these standard ways. By appending special words (commands) to the NAME of the data file when you start one of these programs, you can change their normal operation. Run-time commands are separated from the file NAME and from each other by spaces and/or commas. Note that you need type only the first letter of any command - the rest of the command name is ignored. In the following descriptions, names enclosed in angle brackets ("<>") are variables that are to be filled in with actual values (e.g. you might type "11" where <ndepths> appears) and anything enclosed in square brackets ("[]") is optional. The first letter of each command is enclosed in parentheses to indicate that only this letter is needed for the command to be recognized. The currently implemented run-time commands are:

(A)tmos Effect=<value>: This causes the value specified after the equal sign to be used as the value of ATMOS_EFFECT (see section 2.1.4) for this run.

(B)reakpoint: This causes YEARPROD or DAYPROD to breakpoint itself (see section 4.3) after checking the input data for errors and computing production for the first date for which production is to be calculated. It allows you to check for bad input data, to see the depths at which calculations are going to be made and to check the magnitude of the calculated values on the first day before committing the machine to a long calculation.

(C)heck: YEARPROD and DAYPROD do not normally check the solar data for errors as they do all of the other input data. You force them to check for errors with this command. The reason for not normally checking these data is that a single solar radiation dataset is typically used for many different stations or for many different lakes. It takes about five times as long to read and check these data during the preliminary error checking phase of the program than it does to check all the other input data combined. Moreover, it is only necessary to check them once (or indeed to not check them at all, e.g. when the program has generated simulated cloudless weather).

(I)ntervals=<ndepths>: This sets the number of depths at which production will be calculated to <ndepths>. If this command is not specified, ndepths defaults to 11. Because of the integration algorithm used (see section 2.1.3), <ndepths> must be an odd number. To assure reasonable accuracy values less than five are not allowed. If more than 41 intervals are needed then the program must be recompiled after changing the value of MAXINTR in the file PRODN.REP.

(L)atitude=<degrees>: This sets the latitude of the waterbody to the value specified after the equal sign. The value of latitude is used to calculate cloudless surface irradiances and is irrelevant if you are using empirical surface light data. Enter values for the southern hemisphere as negative numbers.

(O)utput=<drive>: This command allows you to specify the disc drive (A - P) on which the output file for this run will be written. Normally the output files are written onto the default drive (see the CP/M manual for the definition of drive nomenclature).

(S)olar=<drive>: This command allows you to specify the disc drive (A - P) on which the solar data for this run is to be found. By putting the solar data on the second drive, you can make more space available on the default drive for output files.

(U)niform: This causes the input data values for chlorophyll, α and P_m^B to be applied uniformly over the input depths instead of being linearly interpolated. An example will make this clear: Suppose that the input data looked like:

```
|MAY 5  0.0  10,  5.0  100,  10.0  1000, -1
```

If the Uniform command is given then all depths between 0 and 4.99 meters will be assigned the value 10, depths between 5 and 9.99 meters will be assigned the value 100 and any depths greater than 10 meters will be assigned the value 1000. If you do not specify this command then values will be linearly interpolated: if calculation depths are at 0, 1, 2, etc. then the interpolated values for the above dataset would be 10, 28, 46, etc.

(Z)max[=<maxdepth>]: In a shallow lake the calculated euphotic zone depth might be greater than the actual maximum depth of the lake. There must, therefore, be some way of forcing the program to use the maximum depth input in the transparency data as zmax rather than the maximum calculated euphotic zone depth. This is accomplished with this command. You can also force the program to use a predetermined maximum depth by specifying a value after the equal sign.

Some examples are:

```
A>YEARPROD ELA84,Z,B,I=15
```

This run will use the maximum depth in the input transparency data as zmax, it will calculate production at 15 depth intervals and it will automatically breakpoint itself after calculating the first days' results.

```
A>YEARPROD WPG76,Z=10.5,L=53,C,S=B,O=B
```

This run will use 10.5 meters as the maximum depth, 53 degrees for the latitude if cloudless irradiances are calculated, the solar irradiance data will be checked for errors before doing the calculations, solar data will be read from disc drive B, and the output file (WPG76.OUT) will be written on drive B.

5. EXAMPLES

This section shows the output produced by the model given the example datasets in section 3 as inputs.

5.1 PROGRAM FITSOLAR

This program is interactive with the terminal. The output below shows a session with this program. As before, user inputs are underlined, program output appears in bold typeface.

```
A>fitsolar

FITSOLAR  Version 3.0  20/SEP/84

FWI Software Tools

Enter year (e.g. 1980): 1984

Enter latitude in degrees: 50


Enter date (e.g. May 1): jun 21
Enter surface irradiance at noon: 125.5
ATMOS_EFFECT =  0.3635

Enter date (e.g. May 1): may 2
Enter surface irradiance at noon: 115
ATMOS_EFFECT =  0.3677

Enter date (e.g. May 1): ^C
```

The symbol "^C" stands for Control-C and is obtained by pressing "C" while holding down the "control" key. This is the way that you terminate this program.

5.2 PROGRAM PSPARMS

If the data shown in section 3.3 are in a file called TESTPRM.INC, then typing

A>psparms testprm

should produce the following output in the file TESTPRM.PRM:

```
Yellowknife Lake Study, 1983 Data
Identifier          #Iter  Chl  PBm  Alpha Sum.Sq Est.Err
=========================================================
Station_01            30   5.7  0.55  1.48  0.011  0.077
Station_75            17   2.6  1.95  4.77  0.440  0.247
```

This output is interpreted in the following way:

- o The first line is the header for the entire dataset.
- o The second line shows what the columns of calculated results contain.
- o The results follow:
  - Column 1 is the experiment identifier. If this identifier is longer than 20 characters it will be truncated to this length.
  - Column 2 shows the number of iterations that were required for convergence to the best estimates.
  - Column 3 shows the chlorophyll concentration.
  - Column 4 shows the best estimate of P^B_m.
  - Column 5 shows the best estimate of α.
  - Column 6 shows the final sum of squares of the deviations between the best fit of the photosynthesis equation given in section 2.4 and the experimental data. If this number is unusually large you should check your input data for errors.
  - Column 7 shows the estimated error (= the standard deviation divided by the number of data points minus the number of parameters that were fit (2)). If this number is unusually large you should check your input data for errors.

While this program is running it displays on the screen the values of P^B_m, α, and the sum or squares for each iteration. This is done primarily to assure you that the machine is not "dead". You can also use this information to speed up the parameter estimation procedure: Because of arithmetic round-off errors, it is possible for the program to get "stuck" after it has converged to an acceptable solution. This is what is happening when the parameter values that appear on successive iterations alternate between two very slightly different values and the sum of squares doesn't change. If you aren't concerned with wasting computer time you can just let the program go on and it will stop itself after 100 iterations. However, you can keep it from making unnecessary iterations by pressing the "B" key. This causes the program to give up on the current dataset and go on to the next.

5.3 PROGRAM YEARPROD

If the data shown in section 3.4 are in a file called TESTYR.DAT and if neither 1969.SOL nor CLDLSS.SOL exist on the disc, then typing

A><u>yearprod testyr</u>

should produce two disc files:

o A file called CLDLSS.SOL that contains simulated cloudless irradiances for the period for which production was simulated:

```
Cloudless light data for 1976   latitude = 50.0   atmos_effect = 0.3563
MAY  1
   0.0   5.4  16.2  27.1  38.0  48.8  59.2  69.0  78.1  86.4  93.6  99.7 104
 108.1 110.2 110.9 110.2 108.1 104.6  99.7  93.6  86.4  78.1  69.0  59.2  48
  38.0  27.1  16.2   5.4   0.0  -1.0
MAY  2
   0.0   6.0  16.7  27.6  38.6  49.3  59.7  69.5  78.6  86.9  94.1 100.2 105
 108.6 110.7 111.4 110.7 108.6 105.0 100.2  94.1  86.9  78.6  69.5  59.7  49
  38.6  27.6  16.7   6.0   0.0  -1.0
MAY  3
   0.0   6.5  17.3  28.2  39.1  49.8  60.2  70.0  79.1  87.4  94.6 100.7 105
 109.0 111.2 111.9 111.2 109.0 105.5 100.7  94.6  87.4  79.1  70.0  60.2  49
  39.1  28.2  17.3   6.5   0.0  -1.0
MAY  4
   0.0   7.1  17.8  28.7  39.6  50.4  60.7  70.5  79.6  87.8  95.0 101.1 106
 109.5 111.6 112.3 111.6 109.5 106.0 101.1  95.0  87.8  79.6  70.5  60.7  50
  39.6  28.7  17.8   7.1   0.0  -1.0
MAY  5
   0.0   7.6  18.3  29.2  40.1  50.9  61.2  71.0  80.1  88.3  95.5 101.6 106
 109.9 112.1 112.8 112.1 109.9 106.4 101.6  95.5  88.3  80.1  71.0  61.2  50
  40.1  29.2  18.3   7.6   0.0  -1.0
MAY  6
   0.0   8.1  18.9  29.7  40.6  51.3  61.7  71.5  80.6  88.8  96.0 102.0 106
 110.4 112.5 113.2 112.5 110.4 106.8 102.0  96.0  88.8  80.6  71.5  61.7  51
  40.6  29.7  18.9   8.1   0.0  -1.0
MAY  7
   0.0   8.7  19.4  30.2  41.1  51.8  62.2  71.9  81.0  89.2  96.4 102.5 107
 110.8 112.9 113.6 112.9 110.8 107.3 102.5  96.4  89.2  81.0  71.9  62.2  51
  41.1  30.2  19.4   8.7   0.0  -1.0
MAY  8
   0.0   9.2  19.9  30.7  41.6  52.3  62.6  72.4  81.5  89.6  96.8 102.9 107
 111.2 113.3 114.0 113.3 111.2 107.7 102.9  96.8  89.6  81.5  72.4  62.6  52
  41.6  30.7  19.9   9.2   0.0  -1.0
MAY  9
   0.0   9.7  20.4  31.2  42.1  52.8  63.1  72.8  81.9  90.1  97.2 103.3 108
 111.6 113.7 114.4 113.7 111.6 108.1 103.3  97.2  90.1  81.9  72.8  63.1  52
  42.1  31.2  20.4   9.7   0.0  -1.0
MAY 10
   0.0  10.2  20.9  31.7  42.6  53.2  63.5  73.3  82.3  90.5  97.7 103.7 108
 112.0 114.1 114.8 114.1 112.0 108.5 103.7  97.7  90.5  82.3  73.3  63.5  53
  42.6  31.7  20.9  10.2   0.0  -1.0
```

o A file called TESTYR.OUT that contains the computed productivity profiles for each day, for the entire time period simulated, and the integrals of all of these profiles. The second half of the output contains the input data as interpolated at the depths where calculations were made and the warning messages for this run:

Lake Winnipeg 1976, Cruise 3

	mg/sqm	0.00	1.20	2.40	3.60	4.80	6.00	7.20	8.40	9.60	10.80	12
		Depths (mg C/(m**3.day))										
MAY 1	171	28	27	26	24	20	14	8	5	2	1	
MAY 2	343	56	55	52	49	41	28	17	9	4	2	
MAY 3	517	85	82	79	73	62	43	26	14	7	3	
MAY 4	693	114	110	106	98	83	57	35	19	9	3	
MAY 5	870	143	139	133	123	104	72	43	24	12	4	
MAY 6	1049	172	167	160	148	126	87	52	29	14	5	
MAY 7	1229	201	195	187	173	148	102	62	34	16	6	
MAY 8	1410	230	224	215	199	170	117	71	39	19	7	
MAY 9	1593	259	253	242	225	192	133	80	44	21	8	
MAY 10	1777	289	281	270	251	214	149	90	49	24	9	
total (gm)	9.7	1.6	1.5	1.5	1.4	1.2	0.8	0.5	0.3	0.1	0.0	

(a new page starts here)

INPUT DATA

	0.00	1.20	2.40	3.60	4.80	6.00	7.20	8.40	9.60	10.80	12
	Depths										
Light extinction: % of Surface Light											
MAY 1	100.00	57.54	33.11	19.05	10.96	6.31	3.63	2.09	1.20	0.69	0
MAY 5	100.00	57.54	33.11	19.05	10.96	6.31	3.63	2.09	1.20	0.69	0
MAY 10	100.00	57.54	33.11	19.05	10.96	6.31	3.63	2.09	1.20	0.69	0
Chlorophyll: mg/(m3)**											
MAY 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1
MAY 10	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10
alpha: mg C/(mg chl.E.m-2)**											
JAN 1	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5
MAY 10	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5
PBm: mg C/(mg chl.hr)											
MAY 1	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1
DEC 31	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1

Lake Winnipeg 1976, Cruise 3
Cloudless light data for 1976   latitude = 50.0   atmos_effect = 0.3563
=> TESTYR Light extinction data on MAY 5 extended to start date

```
=> TESTYR alpha data on JAN 1 extended to finish date
=> TESTYR PBm data on DEC 31 extended to start date
=> TESTYR Light extinction data on MAY 5 extended to finish date
```

5.4 PROGRAM DAYPROD

If the example data sets in section 3.5 are in a disc file called TESTDAY.DAT and 318.STA, respectively, and if there are no solar data on the disc then typing

A>dayprod testday

should produce the following output in the file TESTDAY.OUT:

```
L. Wpg, Station 318, 1976   Cloudless weather
                                                    Depths
                   0.00  0.30  0.60  0.90  1.20  1.50  1.80  2.10  2.40  2.70  3
        mg/sqm ------------------------- mg C/(m**3.day) --------------------
JUN  6    137 |  119   113   102    80    51    29    14     6     2     0

                                        I N P U T   D A T A

Light extinction: % of Surface Light

JUN  6        100.00 56.37 31.78 17.91 10.10  5.69  3.21  1.81  1.02  0.57  0

Chlorophyll: mg/(m**3)

JUN  6           1.70  1.70  1.70  1.70  1.70  1.70  1.70  1.70  1.70  1.70  1

alpha: mg C/(mg chl.E.m**-2)

JUN  6           5.40  5.40  5.40  5.40  5.40  5.40  5.40  5.40  5.40  5.40  5

PBm: mg C/(mg chl.hr)

JUN  6           4.70  4.70  4.70  4.70  4.70  4.70  4.70  4.70  4.70  4.70  4

Lake Winnipeg 1976, Cruise 3
Latitude = 50.0      atmos_effect = 0.3563
```

The format of these results is the same as for YEARPROD (section 5.3).

5.5 PROGRAM YTOTALS

If the disc contains the TESTYR.OUT and CLDLSS.SOL files produced by the example run in section 5.3 and if the example data shown in section 3.6 are contained in the file TESTYR.DAT then typing

A>ytotals testyr,i=41

should produce a file called TESTYR.TOT that contains:

Lake Winnipeg 1976, Cruise 3

		Uncorr.		Morphometry Corrected						mean ligh	
	Epi	mg C/m2		mg C/m2		mg C/m3		Mass Produced, gm C		mE/m2.min	
	Depth	Total	Epi	Total	Epi	Total	Epi	To zmax	In Epi	Epi	Hyp
MAY 1	3.00	169	80	145	76	18	27	4.02E+008	2.10E+008	35.93	4.9
MAY 2	3.60	342	191	293	179	36	53	8.13E+008	4.96E+008	32.97	4.0
MAY 3	3.60	518	288	442	269	54	80	1.23E+009	7.47E+008	33.21	4.0
MAY 4	4.20	693	443	592	409	73	106	1.65E+009	1.14E+009	30.62	3.3
MAY 5	4.20	871	557	745	515	91	133	2.07E+009	1.43E+009	30.83	3.3
MAY 6	4.80	1049	749	897	685	110	157	2.49E+009	1.90E+009	28.60	2.7
MAY 7	4.80	1229	875	1050	801	129	183	2.92E+009	2.23E+009	28.79	2.7
MAY 8	4.80	1412	1006	1206	920	148	210	3.35E+009	2.56E+009	28.97	2.7
MAY 9	5.40	1594	1241	1361	1124	167	231	3.78E+009	3.12E+009	27.02	2.2
MAY 10	5.40	1779	1383	1519	1253	187	258	4.22E+009	3.48E+009	27.19	2.2
totals (gm)		9.7	6.8	8.2	6.2	1.0	1.4	2.29E+010	1.73E+010		

Maximum depth = 12.00

Number of depth intervals = 41
Cloudless light data for 1976   latitude = 50.0   atmos_effect = 0.3563

Note that the uncorrected integrals (col. 4) do not exactly match the corresponding results in the file TESTYR.OUT (section 5.3) that was used as input to this program. The reason for this is that the integrals reported by YTOTALS were calculated with 41 depth intervals while those calculated by YEARPROD were calculated with only 11 depth intervals. The reason for using more depth intervals in the TOTALS programs was discussed in section 2.5.

5.6 PROGRAM DTOTALS

If the disc contains the TESTDAY.OUT file produced by the example run in section 5.4 and if the example data shown in section 3.7 are contained in the file TESTDAY.DAT then typing

```
A>dtotals testday,i=41
```

should produce a file called TESTDAY.TOT that contains:

L. Wpg, Station 318, 1976 Cloudless weather

		Uncorr.		Morphometry Corrected						mean ligh	
	Epi	mg C/m2		mg C/m2		mg C/m3		Mass Produced, gm C		mE/m2.min	
	Depth	Total	Epi	Total	Epi	Total	Epi	To zmax	In Epi	Epi	Hyp
JUN 6	10.00	137	137	133	133	17	17	3.69E+008	3.69E+008	5.03	0.0

Maximum depth = 10.00

Lake Winnipeg 1976, Cruise 3
Latitude = 50.0 atmos_effect = 0.3563
Number of depth intervals = 41

ACKNOWLEDGMENTS

Gordon Buchanan answered my questions about PL/I and CP/M with good cheer and great skill. He also supplied the 8080 assembler routines described in Appendix 1. Susan Kasian suggested the organization of the manual. Bob Hecky encouraged the project. Dave Hayward and John Shearer tested the programs and made suggestions that shaped their design.

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APPENDIX

This appendix lists the disc files that contain the source code for the productivity model. Files with "CP/M" in the right margin contain CP/M specific code that will need modification for other operating systems.

Global Declarations Files

GENERAL.GLO	Numeric variables used by all programs
PRODN.BIT	Boolean variables
PRODN.FIL	Files
PRODN.GLO	Numeric variables used by YEARPROD and DAYPROD
PRODN.MTH	Calender variables
PRODN.REP	Constants
TOTALS.GLO	Variables used by YTOTALS and DTOTALS

PL/I Files

ABORT.PLI	Prints error message and stops	
ADJDAT.PLI	Interpolates data for YTOTALS and DTOTALS	
BRKPOINT.PLI	Breakpoints the output file and stops	
CALCPARM.PLI	Interpolates data for YEARPROD and DAYPROD	
CALCZEUP.PLI	Returns the depth of the euphotic zone	
CALCZMAX.PLI	Returns the depth of production profile calculations	
CALENDER.PLI	Sets up the Julian calender	
CHKDATA.PLI	Determines data availability for YEARPROD and DAYPROD	
CNVRTDRV.PLI	Converts a disc drive specifier	CP/M
COPYF.PLI	Copies a file, then deletes it	
DALYRATE.PLI	Computes daily production profile and integral	
DATACHK.PLI	Determines data availability for for YTOTALS and DTOTALS	
DAYPROD.PLI	DAYPROD main program	
DELREN.PLI	Deletes old disc file and names new file	CP/M
DTOTALS.PLI	DTOTALS main program	
ECHOYEAR.PLI	Summarizes an input dataset for YEARPROD	
ERASE.PLI	Deletes a disc file	CP/M
FINSHDAY.PLI	Summarizes all input data for DAYPROD	
FINSHTOT.PLI	Summarizes totals for YTOTALS	
FINSHYR.PLI	Summarizes all input data for YEARPROD	
FITSOLAR.PLI	FITSOLAR main program	
FMJULIAN.PLI	Converts Julian date to day and month	
GENSOL.PLI	Generates cloudless solar irradiance data	
GETDATA.PLI	Gets depth profile data	
GETFILE.PLI	Gets a data file	
GETHYPSO.PLI	Gets hypsographic data	
GETIZERO.PLI	Gets surface irradiance data	
GETPARM.PLI	Gets parameters	
GETZEPI.PLI	Gets the depth of the epilimnion	
HEADER.PLI	Prints depths of calculation	
INITDAY.PLI	Opens files and initializes variables for DAYPROD	
INITDTOT.PLI	Opens files and initializes variables for DTOTALS	
INITYEAR.PLI	Opens files and initializes variables for YEARPROD	
INITYTOT.PLI	Opens files and initializes variables for YTOTALS	

INPUTXY.PLI	Reads paired x, y values from a file	
INTEGRAT.PLI	Integrates an array using Simpson's Rule	
MKTMPFIL.PLI	Puts input data into temporary files	CP/M
NINDEX.PLI	Miscellaneous PL/I string function	
NSUBSTR.PLI	Miscellaneous PL/I string function	
OPENF.PLI	Opens a file	
PCLINE.PLI	Processes the control line	CP/M
PRTTOTL.PLI	Splits production into mixed layer and hypolimnion totals	
PSPARMS.PLI	PSPARMS main program	
READDATA.PLI	Inputs raw data	
REGER.PLI	Linear regression	
SEPNAME.PLI	Separates CP/M file name into its parts	CP/M
SETDTOTL.PLI	Gets files for DTOTALS program	
SETUPFIL.PLI	Sets up output file for DAYPROD program	
TOJULIAN.PLI	Converts day and month to Julian date	
TRIM.PLI	Miscellaneous PL/I string function	
TUPPER.PLI	Miscellaneous PL/I string function	
VERSION.PLI	Displays version identifier	
WARN.PLI	Prints warning message	
WHCHLITE.PLI	Determines existence of solar irradiance data file	
WRAPUP.PLI	Copies warning messages to end of output	
YEARPROD.PLI	YEARPROD main program	
YTOTALS.PLI	YTOTALS main program	

Assembler Files

CONIO.ASM	Console character input/output	CP/M
DELFILE.ASM	Deletes a disc file	CP/M
RENFILE.ASM	Renames a disc file	CP/M

The four system specific "primitives" coded in assembler will have to be recoded for other operating systems. The specifications of these procedures are:

o CONRDY - returns '1'b if the user has pressed a key.

o CONIN - returns a character from the keyboard.

o DELFILE - erases the disc file whose name is sent to it as a character string.

o RENFILE - accepts two character strings as input and renames the disc file that has the name of the first string to the name given in the second string.

The model needs these procedures so that you can interrupt it and later restart it at the place where it was interrupted. On mainframe computers you won't need to (or be allowed to) "breakpoint" the program and you can simply remove all references to these procedures.